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There's More to Harvesting Than Green Timber and Sawlogs:
Engineering Forest Operations for 21st-Century Forest Management

When Congress established the U.S. Forest Service in 1905 to provide quality water and timber for the nation's benefit, living trees or "green" timber was implicitly understood as the source of this timber. Private timberland landowners similarly prioritized the growing and harvest of merchantable green timber for use in the manufacturing of high-value forest products such as lumber. Though dead trees have always been a component of the log supply, forest operations, supply chain logistics, sawmill design, and economic models all coalesced around the model of maximizing the efficiency of handling and processing green timber.

Because of evolving societal values and fire management in a changing climate, today's foresters must manage forested landscapes to meet a wide range of objectives in addition to the production of merchantable green timber. Forest treatments are conducted to reduce fire risk on the landscape, promote forest health, salvage timber following a natural disturbance, reforest burned areas, improve wildlife habitat, and meet other objectives.

In these situations, it's often smaller-diameter green trees and dying or dead trees that make up a larger portion of the harvest. Unfortunately, the markets for these materials, such as pulp logs, firewood, posts and poles, hog fuel, and biomass, all generate less revenue than traditional sawlog markets. And that's if a market for these materials even exists.

In some areas of the Intermountain West, primary forest industry has been shuttered, and hauling logs and biomass to a facility a hundred miles away can cost more than the delivered value of the materials.

These market and economic conditions can dissuade foresters or land managers from prescribing these types of treatments if their budget cannot bear the

Contractors harvest beetle killed timber and biomass within a fuels treatment on the Helena National Forest to protect the Helena municipal watershed. USDA Forest Service photo by N. Anderson.

cost. Yet these types of harvests are desperately needed to improve forest health and reduce fire risk, so what can they do?

Early in their research to identify cost-effective methods for harvesting and transporting beetle-killed timber and biomass, the team members of the Feedstock Logistics & Processing task areas of the Bioenergy Alliance Network of the Rockies (BANR) realized that common models based on green timber failed to account for the harvest logistics and economic realities of this type of harvest.

Instead, new models were needed to address the on-the-ground conditions that foresters faced when deciding whether to harvest stands in various stages of insect or pathogen infestation and mortality. Models demonstrated how harvest operations could be conducted more efficiently and safely; other models estimated a more accurate economic value of salvaged timber and biomass in the marketplace.

Nate Anderson, a research forester with the Rocky Mountain Research Station and member of the team, says that their biomass work raised some eyebrows of those in the forest products industry and research community. "We were told, 'Why the heck are you guys working on forest operations and biomass logistics in 2018?" he recalled. "We did tons of work on biomass in the late '70s after the fuel crisis.'"

To the critics, Anderson would counter that the research was indeed both relevant and contemporary. "A lot of the models developed in the golden age of forest engineering in the mid-20th century were developed for timber production," he explains. "If we try to import those over to our current land management environment, with its different regulatory environment and forest products markets, and an emphasis on managing for multiple ecosystem services, the models don't transfer very well."

What follows is an overview of the team's key findings that are relevant to today and future forest management and economic realities. For the BANR research, "We used beetle kill salvage as the lever we were pulling to study its effects on harvest operations and markets," Anderson says. "But the research cuts across traditional timber sales of live standing trees, fire salvage, and reducing fire impacts with fuel treatment."

Sawlogs all the way

When the BANR project launched in 2013, the mountain pine beetle outbreak in the Rockies had been underway for nearly 10 years. This time lag afforded Anderson and his team the opportunity to quantify how the forest products markets responded to the transition from green timber to dead timber.

After interviewing sawmill managers and wood procurement

BANR | BIOENERGY ALLIANCE NETWORK OF THE ROCKIES

What is the Bioenergy Alliance Network of the Rockies?

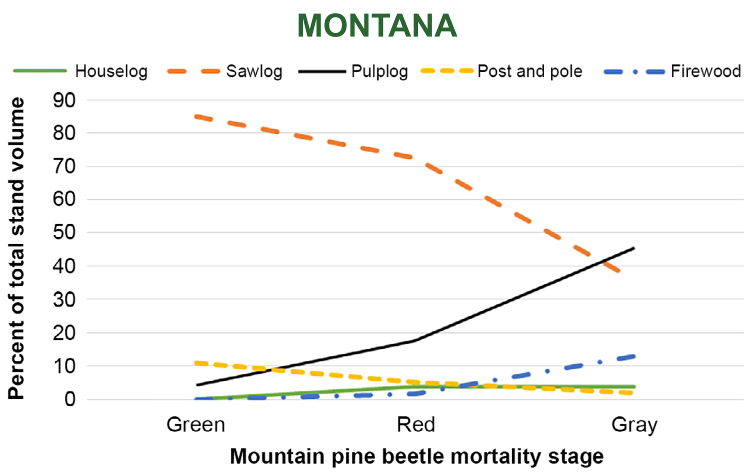
The mountain pine beetle outbreak of the early 2000s resulted in over 42 million acres of dying or dead trees in the Rocky Mountain region. If Canada's mortality is included, the total loss spans more than 60 million acres.

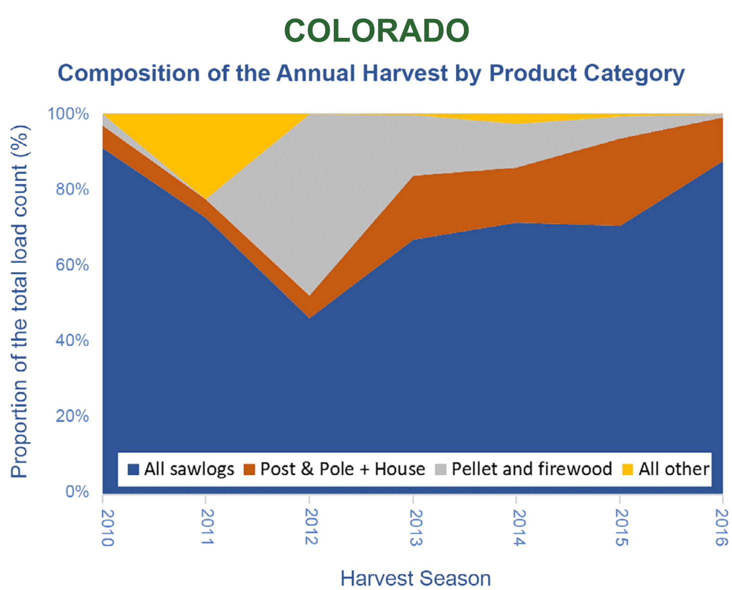
In 2013, the USDA National Institute of Food and Agriculture awarded $10 million to the Bioenergy Alliance Network of the Rockies (BANR), a 5-year project led by Colorado State University that brought together scientists, extension agents, and educators who hailed from state and federal agencies, academia, and industry to provide the scientific underpinnings for a new bioeconomy focused on creating economic value from beetle-killed timber and biomass.

A number of researchers from the Rocky Mountain Research Station were members of the five major BANR task areas to provide expertise in their respective fields. These five task areas were Feedstock Supply; Feedstock Logistics & Processing; System Performance & Sustainability; Education, and Extension Outreach and Health & Safety.

While forest biomass demand remains relatively small in this region for a variety of reasons, the research is invaluable to inform both forest management and the development of new ventures.

At sawmills across the country, having a dependable sawlog supply is necessary to produce a steady supply of lumber for markets. Disturbances, such as wildfires or insect outbreaks, can cause gluts or shortages of these sawlogs. USDA Forest Service photo by N. Anderson





staff in Montana and Colorado, the team learned the extent to which sawmills prioritized purchasing green timber that is classified as sawlogs. (Sawlogs are the backbone of the industry since they are milled into lumber.) If green sawlog availability decreases, the sawmills may transition to purchase dead timber that still meets their specifications for milling.

While it's still possible to obtain some lumber from low-grade logs that have been dead for many years, the quality and volume isn't comparable to green sawlogs. Generally, depending on species, value can decline rapidly as affected trees die and decay. Where markets exist, and depending on its quality, much of the low-grade material may go to wood pulp used in the manufacturing of paper or cardboard or to energy uses. However, these uses tend to bring in less revenue than sawlogs by volume.

In both Montana (top left, from Loeffler and Anderson 2018) and Colorado (bottom left, courtesy of Nate Anderson), researchers observed that the harvested timber supplied different markets as the bark beetle outbreak progressed. This reflected the changing quality of the timber being harvested. Green timber represents living trees while red and gray timber represents dying and dead trees, respectively. Notice the shift from sawlogs to other products such as wood for energy in Colorado and greater proportion of pulp logs and firewood in Montana.

When quantifying these changing markets, researchers used different data sources to quantify these changes. In Montana, the percent of total stand volume was used, while in Colorado, researchers used the paper load trip tickets that drivers filled out for each truckload delivered to mills.

When given the opportunity between purchasing green timber or dead timber, the team found that sawmills usually preferred purchasing green timber, in spite of the higher procurement costs (also known as the stumpage cost) because it results in higher profit margins. “This is well known in the industry, so it wasn’t an ‘a ha’ moment,” says Anderson. “But quantifying the affect for a beetle-kill event of this scale helped people understand the impacts for the industry and also how to best plan for and understand those impacts in the event of a future disturbance.”

Anderson adds the caveat that this preference could vary based upon region. For example, in Colorado, local mills got to a point where they preferred the dead lodgepole over the green timber, says John Twitchell, a supervisory forester with the Colorado State Forest Service. He attributes this to the lower moisture content of the dead wood that, if it was kiln dried, needed less time and energy.

A finding that struck Anderson was the need to make the decision of whether to harvest or not once tree die-off is observed, particularly if foresters want to recoup the costs of implementing a treatment from the sale of timber and other materials.

While it’s legitimate to decide not to harvest, “Do not wait 5, 8, 10 years to make a decision [following a natural disturbance],” Anderson cautions. “We have quantified the costs of delay and they are severe. Not just in terms of money but in terms of health and safety and other aspects of operations.”

The safety considerations that Anderson mentions are the dead and dying trees within a stand. These pose a risk to on-the-ground forestry personnel, and during harvest operations, operators work more slowly in order to maintain safe operating conditions and handle difficult breaking, falling, and down wood in the stand. This in turn can further decrease the productivity of an operation.

How much volume is in that dead tree?

In preparation for a treatment or harvest, producing accurate estimates of the merchantable stand volume is necessary to determine its market value as a sale and whether a contractor or sawmill might even bid on

Summary

For most of the 20th century, a primary objective of forest operations on federal public lands was supplying green timber to the forest products industry for manufacturing lumber and other forest products. Harvest operations and supply chain logistics were designed to handle this green timber with methods that maximized both efficiency and productivity with an eye on revenues.

Today, managers are planning forest operations for many reasons besides harvesting green timber, including reducing fire risk on the landscape, promoting forest health, restoring damaged forests, or salvaging timber following natural disturbance. These types of operations have diverse objectives and have different economic, environmental, and safety considerations compared to green timber harvests. Smaller diameter trees or dead and damaged timber are often removed as partial harvests rather than clear cuts. Conducting salvage operations is more hazardous due to risks associated with standing dead trees. These harvests also produce lower-grade, lower-value products such as pulp logs, firewood, and biomass and are often more costly to conduct.

A team comprised of researchers from the USDA Rocky Mountain Research Station (RMRS), the University of Idaho, and Oregon State University, who were members of the Bioenergy Alliance Network of the Rockies (BANR), studied how salvage operations conducted in beetle-killed stands could be made more efficient and safer. By improving the use of real-time data collection and lidar in forest operations, they found that customizing harvest systems and logistics at the landscape scale improved the safety and efficiency of the harvests and expanded options for biomass utilization while also meeting ecological objectives.

Although the team’s research focused on salvage logging in beetle-killed stands, their findings can also inform present and future forest operations in green stands and forests impacted by other types of disturbance. When hazardous fuels reduction and forest restoration are primary forest management goals, investment in preplanning to optimize harvest logistics can reduce costs and risks during these types of treatments. When contractors see the value of upgrading to cutting-edge logging technology, they can make investments to operate more efficiently and safely in difficult environments with challenging silvicultural prescriptions. Forest managers can also anticipate how industry is likely to respond to a new supply of dead wood into the market when harvest operations commence.

the project. Such estimates also help predict how much logging residue could be delivered to a biomass facility or might have to be burned for disposal if markets are not available. Foresters use mathematical formulas known as allometric equations to estimate aboveground tree biomass and the mass of component parts like the bole, branches, and foliage. Surprisingly, there aren't many allometric equations for western tree species as standing dead trees.

Prior to BANR, "There were not many studies dealing with dead trees so our studies were pretty unique," says Woodam (Woody) Chung, a collaborator of Anderson and a professor at Oregon State University who led this line of research for the Feedstock Logistics & Processing task area while working closely with the Feedstock Supply group.

Observations during their tours of dead lodgepole pine stands in Montana prompted Chung and the team to consider building new allometric equations. "When I looked up at the trees, they looked different [from green trees]," he says. "The dead trees had lost their needles, many of their branches, and the bark is gone too. Many dead trees also didn't have tops, which is why it's dangerous to walk around in dead stands during windy days."

There was clearly less biomass in the canopy and therefore potentially less biomass to harvest. Through the sampling of 14 lodgepole pine trees in the northern Colorado Rocky Mountains (7 live and 7 mountain pine beetle-killed), researchers developed allometric equations for these dead and dying trees. Chung and the team found that there was no significant difference in aboveground (bole and branch) biomass between live and dead trees; it's the bole portion that is typically valued as a sawlog or pulp log.

However, the beetle-killed trees had a 50 percent reduction in other forms of biomass because of the loss of needles, tops, and bark; these components are the logging residue that is typically sold as biomass feedstock. "If you use live tree allometric equations to estimate how much logging residue you'd get from a dead stand, you'll overestimate by 50 percent," cautions Chung.

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Since this study focused on lodgepole pine in Colorado, these allometric equations may not be directly applicable to other regions and species. However, with these equations foresters can obtain a better picture of the approximate biomass on the landscape if there is an option to sell the logging residue to a biomass facility and be conservative in their estimates for dead stands.

Beefing up efficiencies in harvest operations

The BANR Feedstock Logistics & Processing group also calculated the differences of logging costs and contractor productivity when harvesting green trees compared to dead trees in various stages of mortality. "People who have been doing salvage logging might have a feeling it will take a longer time or be less productive if they deal with dead trees, but they hadn't quantified it," Chung says.

The team conducted three detailed time studies of contractors operating in beetle-killed lodgepole stands. At a 27-acre regeneration treatment just northwest of Chessman Reservoir in western Montana, the contractor conducted whole-tree harvesting with six pieces of equipment: a feller-buncher, two skidders, a processor, a delimber, and a log loader. At a 4.7-acre clearcut in the Colorado State Forest, the team conducted two detailed time studies of a crew logging a stand of beetle-killed timber: one using the whole tree method of harvest, collecting logging residue at landing to be sold as biomass; and the lop-and-scatter method, with the logging residue left scattered on the unit by the delimber. The equipment portfolio was similar to the Montana site except a processor wasn't used.

The team found that, indeed, at both sites salvage logging of dead timber took longer because the feller-buncher operator took more care to navigate through the downed wood on the ground. Productivity further declined because of the unrecoverable breakage of the timber. There were also safety considerations working among standing dead trees, with broken tops frequently falling from the canopy.

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At the study site in the Colorado State Forest, the distance the skidder traveled between the landing and stump was the determining factor of whether it was profitable to collect logging residue. "On average, about 800–900 feet of travel distance for the skidder was the breakeven point," says Chung. "If the skidder has to travel more than that, then lop and scatter might be your better option."

"Intuitively and instinctively, and by my gut, I knew certain things [about these types of] harvest operations, but that doesn't translate well particularly when you're trying to tell someone else," Twitchell says. "Just even quantifying the extra seconds, that was important for the economics of production."

From these operations research studies, Chung says, there is now better estimation of costs and revenue when foresters consider whether selling logging residue for biomass may be profitable. "A lot of people think the biomass is free stuff you can just pick up at the landing, but it may not be true based on the location of the harvest unit," he cautions.

"Somebody needs to be paid to bring biomass to a facility," Twitchell concurs. "Right now, our challenge is managing at the forest scale."

Another takeaway from these studies is that delaying a harvest, once the decision is made, will increase the harvest costs and decrease product value and associated revenue. "If you have a lot of downed trees in the stand, it's going to cost more," explained Chung. "To avoid that cost increase, you have to enter those stands as soon as possible. That's the message here in terms of costs but it also helps increase revenue because we're not losing value."

It's also important to consider the safety of the contractors on the job. "No one should be hand felling with a chainsaw in dead stands," he cautions. "Mechanized equipment is the only solution."

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Chung says that their results are applicable to harvest operations elsewhere. "No matter what trees you deal with, if you have downed trees, hung up trees, it will take longer to harvest," he explains. "And you will have more of those problematic trees the longer you wait to harvest."

Bringing high-tech to forest operations

Reading topographic maps, walking the stand, and drawing upon experience are trusted methods that foresters and logging contractors use to determine road placement and logging system layout when preparing to implement silvicultural treatments. With airborne lidar capable of creating highly accurate 3D models of landscape topography and vegetation, a team of researchers led by Robert Keefe, an associate professor at the University of Idaho, wanted to see if lidar could improve the staging of harvest systems. If land managers and logging contractors had a better picture of harvest units across the forest, they could better pair harvest systems with the topography and other ground conditions.

"When you're working with the beetle-kill timber, especially, a lot of it is fairly low value so you need to work with the best tools available to maximize your production and ideally minimize your costs," says Ryer Becker, a graduate student in Keefe's Operations Research Lab who was part of the team.

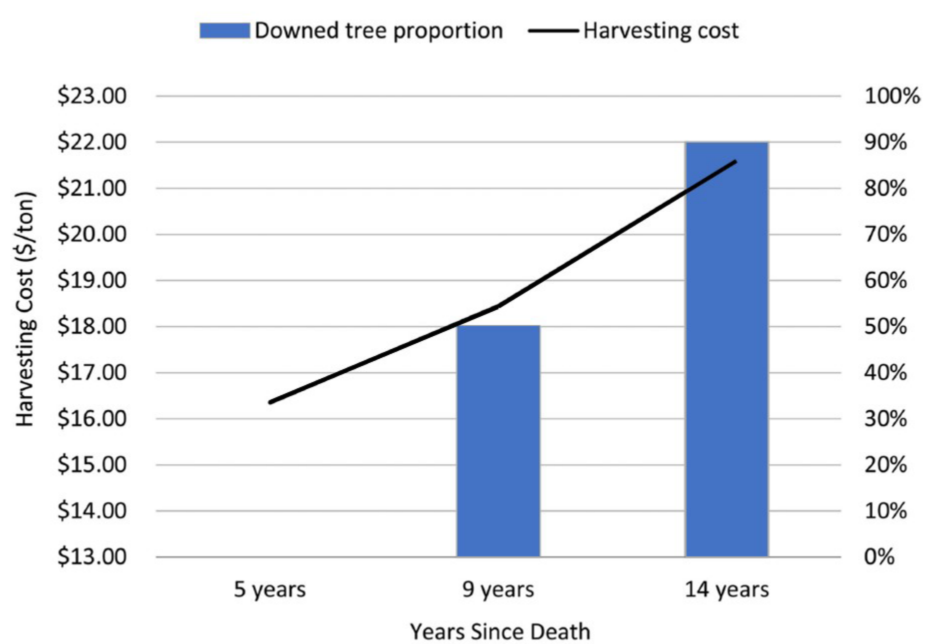
Using lidar data and model simulations, the team tested the operability and efficiency of five different harvest systems deployed in three landscape-scale scenarios on the Slate Creek drainage of the Nez Perce Clearwater National Forest. The harvest systems examined in the study were a feller-buncher with grapple skidder; shovel harvester; tethered shovel harvester; excaliner with hand felling; and swing yarder with hand felling.

Of these harvest systems, the shovel harvester system, especially in a tethered configuration, could be used across much of the steep ground in the study area. Although this system was not being used widely in the Rocky Mountain Region at the time of the study, it's relatively popular in the Pacific Northwest. Model simulations demonstrated that if logging contractors invested in such a machine, it could improve harvesting efficiency at the landscape-scale.

"Our contractors, especially in this region, are really innovative and are always looking for the next and best thing for safety and production reasons," Becker says. Since his research, there has been a gradual increase in the use of shovel and tethered shovel logging use in the region.

Of the maps Keefe's team produced, Anderson sees immediate application: "We can now look at the forest from a planning perspective that is informed by forest operations and new technologies that are coming online, and think about where certain types of harvesting activities make sense not just financially, but from an environmental efficiency standpoint in terms of minimizing negative impacts."

It's this holistic approach that Keefe would readily adopt as manager of the Big Meadow Field Station, University of Idaho's Experimental Forest. "I would start with a map like this and choose which units or parts of different restoration treatments might make sense to include in a management package," he says. "It provides an opportunity to do a landscape-level analysis ahead of time and look at more efficient operations overall. Traditionally, a forester might go out and set up



As the trees decay over the years, there is a corresponding increase in the estimated cost of harvesting biomass. This cost is due to decreased productivity by the operators due to difficult and hazardous working conditions and breakage. Figure courtesy of Yaejun Kim.

some sort of restoration treatment that has 90 percent ground-based equipment and 10 percent steep areas and that may not be appealing to a contractor to bring in steep slope equipment for such a small area. Now you might be able to prioritize the areas where similar logging systems make sense."

Twitchell too sees the value of putting these types of maps in the hands of foresters and contractors. "Right now, we depend upon a logger's and forester's ability to lay out a sale in a manner that allows it to be harvested practically. How do we use all these data in a way that integrates all that?"

Additionally, Becker found that time and motion data of harvesting machines could be gathered in real-time using a Global Navigation Satellite System (GNSS) and radio-frequency technology, which enables the detection of fine movements, such as the grapple swings of a log loader. This research has applications for improving operator safety by alerting personnel to dangerous situations and optimizing

New Biomass Procurement and Supply Chain Analysis Tool

One product produced by the BANR Feedstock Logistics & Processing task areas is a new GIS-based biomass procurement add-in that allows managers to estimate biomass yields and quantify off-road and on-road transportation and other logistic costs across large geographic extents at fine spatial resolutions. Team member John Hogland, a research forester with the Rocky Mountain Research Station, was tasked with developing this software.

"The biomass procurement add-in is based on basic overlay spatial modeling," explains Hogland. "One of the functions within this tool is a path-distance function that converts surface distances to travel times. This path-distance function can be converted into dollars based on machine rates and costs per unit volume removed from the landscape."

Because machine rates and gate prices can fluctuate depending upon the region, the add-in is designed to allow users to input prices generically or in a spatially explicit manner for their region.

Also included in the add-in are spatial, statistical, and machine-learning tools that can be used to estimate species volume composition for a given area.

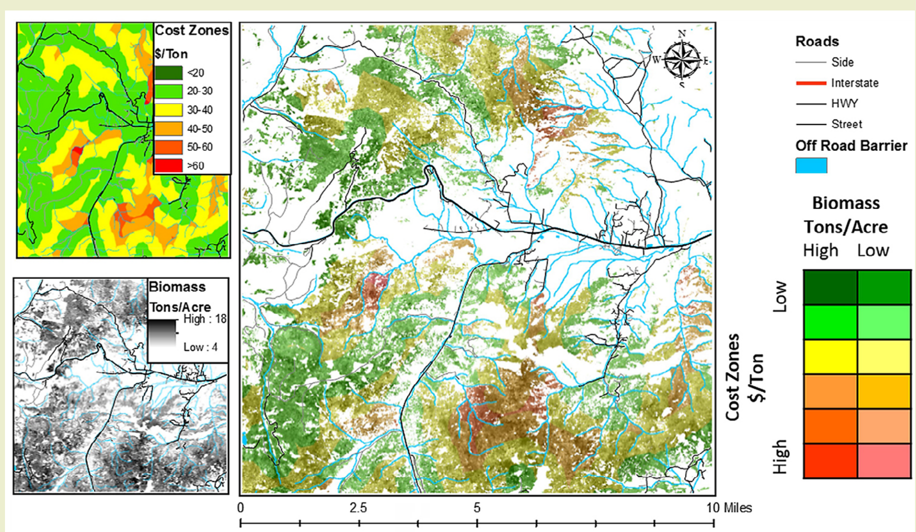
Hogland says that prior to this add-in, managers didn't have a way to look at these data. "People are excited to look at these types of numbers because they're presented in a manner that addresses scope and scale that is intuitive and easy to understand," he says.

Although he cautions that some understanding of special analytics is needed to work within this add-in, Hogland wants decision makers to know these data can be very useful to inform planning.

As a long-time practitioner in the industry, Twitchell foresees a more holistic approach in how forest operations are conducted, which resources such as this GIS-based biomass procurement can help inform. "One of the lessons of BANR that I get excited about is that we need to adapt as practitioners," he says. "We need to be thinking that way in terms of how we change now to adapt to what's coming in the future."

While the add-in is relatively new, Hogland is already working on improvements. "What we're doing now is building a newer rendition that is orders of magnitude more efficient and scales very well across server and desktop platforms," he explains. "It's an ever-evolving thing."

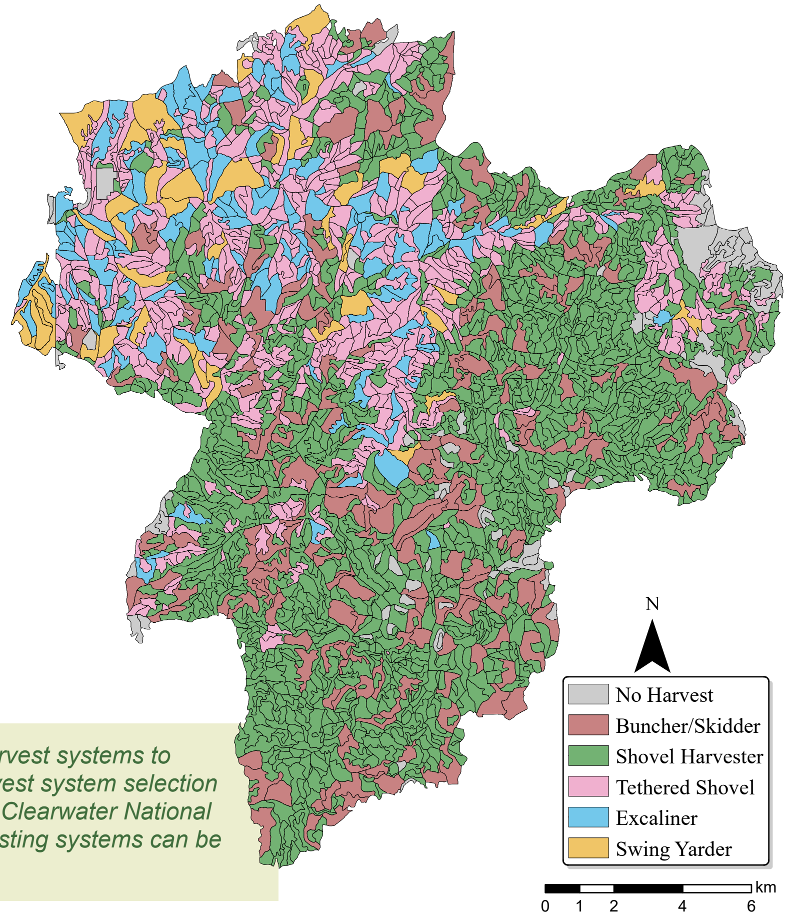
This GIS-based biomass procurement add-in is available at RMRS Raster Utility and the download page. Hogland also has tutorials available.



Above is an example of the outputs from the GIS add-in for biomass and log procurement for a study region near Helena, Montana. Figure USDA Forest Service courtesy of John Hogland.

machine movements, especially because many operators now carry smart phones with GNSS-enabled applications while working. Newer harvesting machines are also equipped with GNSS capabilities. Pairing these with local radio-frequency systems that are not dependent on the cellular network to collect and analyze data in real-time is relatively new and has great potential.

Collectively, this research demonstrates "the use of remote sensing and sensors on the equipment to improve different harvest systems, and is relevant for all harvesting operations," says Keefe. "I would say the use of tools like smart phones to synthesize data in real time at the job site is definitely bigger than BANR and we'll see it used throughout forestry in the near future."



The BANR team developed a lidar-based method to map harvest systems to appropriate units at a landscape scale. With this type of harvest system selection map, such as the above map of 30,000 ha of the Nez Perce Clearwater National Forest, foresters have a high-resolution view of where harvesting systems can be deployed most efficiently. Map courtesy of Ryer Becker.

Creating a harvest system map for your management unit

If lidar and ground plot inventory data have been collected for your management unit, it's possible to create a harvest system map, says Ryan Becker.

For the study area of the Slate Creek drainage of the Nez Perce Clearwater National Forest, Becker created stand polygons that were paired with lidar data. From this pairing, he could make landscape-scale predictions of stand characteristics, such as trees per acre or volume per acre, as well as site-based characteristics, such as slope.

Next, Becker pulled in the transportation network data, which are crucial for determining skidding distance, whether a new road is needed, or hauling distance.

"Once you get this baseline data, now you can ask the question, 'What type of equipment, such as a feller buncher or tethered logging, are we interested in exploring?'" Becker says. "This will vary by landowner or by site. For example, one landowner might be more willing to run a feller buncher on steeper ground than another landowner."

After determining what is the lowest volume of board feet per acre you can harvest without impacting your budget, you will then want to confirm the operable thresholds for your machines. "If you're familiar with harvest operations, you'll have these numbers," Becker explains. "Otherwise, talk with your contractors because they will know better than anybody the limits of the machines and where they will start losing money."

From there, you can review the stands to determine which is a good fit for each harvest system. "There might be overlap between systems where you could choose a couple different options but that comes back on the landowner or management agency," he says.

Of the maps that Becker created for the Nez Perce, he's received positive feedback from staff, and they see the promise of these types of maps for future projects. "There are opportunities to apply this broadly depending on what your objectives are," he says. "This gives you a lot of opportunity to see the landscape even before you get out there."

Key Findings

- Following large-scale disturbance, making timely harvest decisions within 5 years is important. Long delays in conducting salvage operations can greatly increase the cost of operations, decrease the market value of the timber, and increase risks to personnel in the field.
- The financial feasibility of conducting operations for fuels treatment or salvage following a fire or infestation is dependent upon local markets for timber and biomass, such as local sawmilling infrastructure.
- Newly developed decision tools integrating lidar-derived maps of the landscape and harvest system capabilities enable land managers and contractors to identify feasible harvest systems to support the planning of productive, efficient, and environmentally sound forest operations.
- The combination of GPS, radio transmitters, and smartphone technologies can improve worker safety during harvest operations and provide real-time data to measure efficiency and improve performance.

Management Implications

- A new GIS add-in toolset for log and biomass procurement allows managers to better calculate the volume of biomass in a given harvest or treatment area and determine the best harvest and wood procurement logistics.
- When harvesting biomass, selecting the harvest system most suitable to the landscape can reduce the overall cost of the treatment. Additionally, improving transportation efficiencies through the mapping of transportation routes in the GIS-based biomass procurement add-in can be used to identify optimal transportation costs.
- When estimating volume from dead stands, managers can anticipate a 50 percent decrease in biomass compared to green timber biomass because of the loss of needles, tops, and bark; these components are the logging residue typically sold as biomass feedstock.
- Time study (temporal analysis) of forest operations provides detailed data and information that can be used to reduce costs and increase productivity on difficult sites.
- Logging residues are not necessarily a “free” source of biomass at the landing because there may be real costs and opportunity costs associated with production of logging residues.
- Careful design of biomass grinding and transportation logistics can reduce the overall cost of biomass delivery. Slash forwarding for centralized grinding operations can be beneficial if a residue pile is relatively small or located close to a processing site. In-woods grinding can be more cost-effective when large slash piles are highly concentrated in a few locations.
- In planning for future insect, wildfire, or other largescale disturbances, understanding the interactions of forest operations with timber markets and downstream final products will enable managers to plan for how related products may be marketed in the future, which facilitates treatment.

FURTHER READING

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Scientists and Manager Profiles

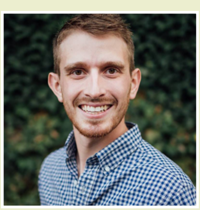
The following individuals were instrumental in the creation of this Bulletin:

Nathaniel (Nate) Anderson is a research forester with the USDA Forest Service, Rocky Mountain Research Station, in Missoula, Montana. He earned an M.S. from the University of Maryland and a Ph.D. from the State University of New York College of Environmental Science and Forestry. Nate's research is focused on forest management and blends silviculture, operations research, and economics.

Woodam (Woody) Chung is the Stewart professor of forest operations with Oregon State University in Corvallis. He earned an M.S. from Seoul National University and a Ph.D. from Oregon State University. Woody's research includes forest operations planning and management, forest biomass, and forest management.

John Hogland is a research forester with the Rocky Mountain Research Station in Missoula, Montana. He earned an M.S. from Auburn University and a Ph.D. from the University of Montana. John's research interests include developing new spatial modeling procedures that quickly process large amounts of data and integrating supply chain models with estimates of forest characteristics derived from high resolution imagery.

Robert Keefe is an associate professor and director of the University of Idaho's Experimental Forest. He has an M.S. and Ph.D. from the University of Idaho. His teaching focus includes forest operations, cable systems, and forest roads.



Ryer Becker is a Ph.D. candidate at the University of Idaho and works in the Operations Research Lab under the direction of Robert Keefe.

John Twitchell is a supervisory forester with the Colorado State Forest Service in Steamboat Springs, CO field office. He has worked in both state and private forestry in New Hampshire, Alaska, and Colorado. John has been a forester with the Colorado State Forest Service since 1998 and managed the Colorado State Forest until 2005. Since that time, he has supervised the Steamboat Springs Field Office in assisting the management of state, private, and federal lands throughout northwest Colorado.

"We can now look at the forest from a planning perspective that is informed by forest operations and new technologies that are coming online, and think about where certain types of harvesting activities make sense not just financially, but from an environmental efficiency standpoint in terms of minimizing impact."

—Nate Anderson

WRITER'S PROFILE

Andrea Watts is a science writer for the Rocky Mountain Research Station and the Pacific Northwest Research Station. In addition to working for the Forest Service, she has written for the Society of American Foresters and several magazines. Her portfolio is available at https//www.wattsinthewoods.com, and she can be reached at andwatts@live.com.

Project Collaborators

Chuck Rhoades, USDA Forest Service, Rocky Mountain Research Station

Rick Bergman, USDA Forest Service, Forest Products Laboratory

Hee Han, Oregon State University

Yaejun Kim, Oregon State University

Lucas Wells, Oregon State University

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Science You Can Use Bulletin

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Nehalem Clark: Bulletin Editor / Science Delivery Specialist
nehalem.clark@usda.gov

Jessica Brewen: Bulletin Editor / Science Delivery Specialist
jessica.brewen@usda.gov

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